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ABSTRACT

This paper summarizes the experience of several pre-college telecommunications projects, with special emphasis on those administered by TERC, including an in-depth account of the evaluation findings in the largest project, TERC Star Schools. It begins by discussing networks and educational change in the context of changing teaching approaches and beliefs, teacher concerns, the role of collaboration, changing patterns of interaction in classrooms, readiness to change, effect on students, and the role of institutions. Collaboration, communication, and learning are then discussed, including student communication and collaboration and teacher collaboration on a network. Patterns of teacher participation are analyzed by contrasting the Science Teachers' Network, which provided teacher support and development but was not specifically linked with any curriculum, and TERC Star Schools, which offered an integrated program that linked technology, curriculum, and teacher support, and documented evidence of changing classroom practices. Several studies dealing with the effect on students of their participation in telecommunications activities are reviewed, with details drawn mainly from two TERC projects: Star Schools and the National Geographic (NGS) Kids Network. Finally, factors involved in predicting network success are discussed, and the major findings from each section are summarized. It is concluded that, when telecomputing is embedded in an integrated program of teacher support and curriculum development, with an involved school administration, it can be a powerful agent of educational change. Additional information about specific networks is provided in 8 notes, and 34 references are listed. (BBM)

Electronic Communities of Learners: Fact or Fiction

Sylvia Weir

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Electronic Communities of Learners: Fact or Fiction

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Contents

Preface

TERC is a nonprofit education research and development organization founded in 1965 and committed to improving science and mathematics learning and teaching. Our work includes research from both cognitive and sociocultural perspectives, creation of curriculum, technology innovation, and teacher development. Through our research we strive to increase knowledge of how students and teachers construct their understanding of science and mathematics.

Much of the thinking and questioning that informs TERC research is eventually integrated in the curricula and technologies we create and in the development work we engage in collaboratively with teachers. Traditionally, TERC staff present their research at conferences and report their studies in journals. By launching the TERC Working Papers series, we hope to expand our reach to the community of researchers and educators engaged in similar endeavors.

The TERC Working Papers series consists of completed research, both published and unpublished, and work-in-progress in the learning and teaching of science and mathematics. We are introducing the series with four papers and will add papers at regular intervals.

Introduction

One way or another, we are all affected by computer networks, whether it be how we bank our money, do our shopping, or book a trip to Hawaii. Educators and researchers at the college level have communicated electronically for more than a decade with colleagues around the world over networks such as Bitnet and Internet. Pre-college educators are becoming increasingly aware of the potential of telecommunications networks to enhance learning, and over the past decade there have been numerous experiments in the use of networks at the primary and secondary levels (Office of Technology Assessment, 1989). The first comprehensive primer on ways of integrating telecommunications into classroom activities has arrived (Roberts, Blakeslee, Brown, & Lenk, 1990).

The benefits of linking microcomputers at one site through Local Area Networks (LANs) are obvious: money is saved on peripherals and software that is networkable, obviating the need for floppies. By 1987-88, a Quality Education Data survey indicated that 64% of 173 of the largest school districts in the United States were networking in this way (Reinhold, 1989). A more substantial and successful use of a LAN is the Bank Street Earth Lab project, which supports a geography-based science curriculum (see Note 1).

The focus of this paper is on networks that link schools across the country and across the globe. Just how extensive these developments are is surprising (Clement, 1992). Many states have set up or are developing plans for networks that link schools across the state (see, for example, Stout, 1992). One of the early projects linking geographically separated schools was the Alaska QUILL Network, set up primarily to connect teachers (see Note 2). Another network focusing on teachers is the Science Teachers' Network at the Educational Technology Center, Harvard Graduate School of Education (see Note 3). TERC's LabNet project links high school physics teachers and students (Gal, 1991; see also Note 4).

Some networks link students, for example, the InterCultural Learning Network (see Note 5): "The goal of the project is for students from different cultures to use each other as resources for learning more about themselves and the social, cultural, and physical world" (Riel, 1987, p. 27). From this grew the AT&T Learning Network (Riel, 1990). Some networks link both teachers and students: TERC and the National Geographic Society (NGS) have brought science telecommunications to elementary teachers and students (see Note 6); TERC's Star Schools project did the same for secondary level teachers and students (see Note 7); and TERC's Global Laboratory project links secondary teachers, students, and scientists (see Note 8).

The motivation behind these developments varies. Some networks are developed as an information source for teachers. Some have an administrative purpose. Others have been set up to bring academic opportunities to isolated rural students. For

many network researchers, the attraction is telecomputing's potential to mediate educational change.

TERC has been at the forefront of work in this area, and a central concern is the role of telecommunications in triggering and supporting educational change. What does it take for meaningful educational change to happen? What are the features of a telecommunications network that would support such change? What are the patterns of network participation by teachers and students? The question is not: What was the effect of having the network?, but rather: In what contexts does the innovation work; what adaptations work with which sets of circumstances? As Bruce and Rubin (in press) write: "The use of an innovation is both a product of the innovation itself and of the social context in which it is placed."

This paper summarizes the experience of several pre-college telecommunications projects, with a special emphasis on those administered by TERC, including an in-depth account of the evaluation findings in the largest project,TERC Star Schools.

Networks and Educational Change

An electronic network can provide a framework for encouraging change within a complex social, interactional setting. Indeed, network projects can serve as an instructive model of how to use technology to provide continuing teacher support while achieving widespread dissemination of innovative ways of encouraging classroom learning. Technology can invite change but does not, alone, ensure it. Educational change involves three components: possible use of new or revised materials; possible use of new teaching approaches; and possible alteration of beliefs (Fullan, 1982).

Several issues provide a framework for discussion.

Changing teaching approaches and beliefs takes time. Introducing innovative curricular approaches can present major hurdles for teacher trainers, and many past failures can be ascribed to the lack of ongoing teacher support. "Change is a process, not an event" (Hall & Hord, 1987, p. 8). Help is most necessary during the activity, and network communication can be designed precisely to provide this ongoing support, providing both an opportunity for information exchange as well an opportunity for genuine discussion about classroom issues. What are the conditions under which this will occur?

Teacher concerns. At its best, the process of introducing innovation should entail mutual adaptation between innovator and consumer. Advocates of the Concerns-Based Adoption Model (Hall & Hord, 1987) stress that many innovations fail not because they are at fault, but rather because the process of implementing them is inadequate. In particular, the views and perceptions of the teachers are not

addressed. Teachers are learners, and learning requires the mutual appropriation of goals. The network can provide a forum for teachers to voice their concerns during the course of the activity. They can participate in determining the nature of the innovation rather than having it thrust upon them. Do teachers take advantage of this opportunity?

The role of collaboration. Building on Vygotsky (1978), the role of collaboration in facilitating learning must be stressed. Learners can achieve much more with help than they can on their own, and a crucial feature of doing things together is talking about them (Weir, 1989). One obvious way in which a network can play a role is its potential to extend opportunities for collaboration and communication, both among teachers and among students. Does this in fact lead to more learning in the classroom? What is the role of curriculum units that specifically require collaboration?

Changing patterns of interaction in classrooms. Teachers who become involved in telecomputing encounter much that is new. They are communicating regularly over distances and over time about their daily activities with people they have never met and who may or may not share their concerns; they are using unfamiliar technology; and, most importantly, they are adapting to changing patterns of interaction in their classrooms. Increased collaboration and communication, both within and across classrooms, create a new kind of learning environment. The existence of a collaborating network with a specific set of objectives could make an enormous difference in how comfortable and successful teachers are with the new ways of working. Working with objectives takes some of the insecurity out of discovery situations (Ennever & Harlen, 1969). How do teachers adapt to changing patterns of control that allow for group activity and peer teaching and learning? And how does the network help them to do this?

Readiness to change. The prospect of educational change does not appeal to all teachers. Teacher-centered instruction is a survival mechanism (Cuban, 1989) and not necessarily something that all teachers find easy to relinquish. Many find the idea too daunting, too difficult to implement. Our focus should be on those teachers who would not change instruction on their own, but could do so if given the right help (Weir, 1989). Consider this learning context in terms of Vygotsky's concept of the zone of proximal development, defined as the "distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). Does the telecommunications network and the activities it promotes act as the zone of proximal development for teachers ready to accept this help?

Effect on students. The effect on students should come in part from how their classroom experiences are changed, but also more directly from their own interactions on the network. What aspects of student behavior are affected and which groups of

students are affected? Of special interest is ascertaining the students' point of view: How do students view their participation on the network?

The role of institutions. Crucial to the whole enterprise is the need for institutional support for the educational changes envisioned. Central to school support is the role of the school principal: "Throughout our years of research and experience, we have never seen a situation in which the principal was not a significant factor in the efforts of schools to improve" (Hall & Hord, 1987, p. 1). How does the attitude of the school administration affect the successful adoption of telecommunications-based activities in a school?

Of all these themes, the role of collaboration and communication is paramount.

Collaboration, Communication, and Learning

Collaboration and communication in a learning situation are theoretically desirable. Since learning involves the internalization of social knowledge, learners need constantly to interact with other people, to do things with others, and to talk to each other about what they are doing (Vygotsky, 1978). Research shows that learning is indeed enhanced during collaborative problem-solving activity. Three examples illustrate.

In bilingual classrooms where children were talking about and working together on tasks using math and science concepts that demanded thinking skills, the more they talked and worked together, the more they learned how to do word problems (Cohen & Intili, 1981). In classroom research on a curriculum using learning centers, children who talked and worked together more showed higher gains on their test scores than children who talked and worked together less (Cohen, 1986). Finally, low-achieving students in fifth- and sixth-grade classrooms showed dramatically increased rates of time on task for those students doing group work as compared to seat work (Cohen, 1986).

Too often, a student's first attempt to communicate on a subject is during a test in answer to an examination question. A student participant in the TERC Star Schools project talks about working in a group of students: "It was better because, you know, people could understand and explain their ideas to us . . . so you would know more about it."

Note that the advantages of group work in a classroom can best be achieved if teachers receive guidance in instituting this kind of change. Obvious problems arise. The ideal is to have a mixed group whose individual members have different strengths to maximize the amount of interpersonal learning that can occur; but how to stop bullies from dominating, retiring children from shrinking even more, socially domi-

nant kids from being listened to more? Cohen (1986) describes specific steps that teachers can take to avoid these problems.

Both students and teachers can increase their collaboration efforts by using an electronic network.

Students Communicate and Collaborate on a Network

Specific benefits for students can be achieved from *distributed science activities*, where the same activity is carried out at sites separated widely geographically, so the results will differ in detail because of different conditions. This allows for cooperative problem solving on a network.

One such activity on the InterCultural Learning Network concerned water shortages and conservation methods used in a number of different countries. An analysis of all the messages sent over the network during the water problem-solving project indicated that a large number of ideas were contributed to the discussion. At the end of the activity, 20 students from an eighth-grade class in San Diego collaborated to write and send a summary message. That message contained 71% of all the ideas mentioned during the entire joint activity. Moreover, among the ideas mentioned by the San Diego students, 66% had been contributed by sites other than San Diego (Waugh, Miyake, Levin, & Cohen, 1988).

Providing a network audience for writing can provide an unexpected effect. Two seventh-grade classes, 22 students in each class, wrote two compositions: one for a regular mid-term examination, and one addressed to peers in other countries on the InterCultural Learning Network. The compositions were graded by the classroom teacher on a 0-100 point scale. The classroom teachers were confident that the examination grades would be higher because students would take more care. They were surprised to find that they had judged the papers that were written to peers on the network significantly higher than those produced for the examination. Two independent raters evaluated the papers with respect to content, organization, vocabulary, language use, and mechanics. The scores on each of these criteria confirmed the superiority of the network compositions; the differences were statistically significant (Cohen & Riel, 1989).

Clearly, specific benefits accrue to students working and communicating collaboratively on a distributed science network; what of teachers?

Teachers Collaborate on a Network

Network exchanges present a prime opportunity for collaboration among teachers. In principle, teachers join a community of learners, where the network becomes the framework for cooperative learning and the scaffolding for teacher learning. The network serves as a forum to share expertise, to try out new ideas, to reflect on

practices, and to develop new curricula. Making a classroom experience public on the network enables participating teachers and students to share a teaching and learning experience. In this way, good teachers can serve as models for others by describing the way they handle particular aspects of the activity.

The record of network exchanges in the TERC Star Schools project (see Note 7) provides examples of effective peer collaboration and learning among teachers. Reflecting on their experiences, some teachers pointed to particular network exchanges that led them to adapt their teaching practices. One teacher wrote to another participant in the TERC Star Schools project, commenting on the value of her exchanges with a more experienced teacher and expressing her thanks:

> It has been a rewarding experience working with you. You are the kind of teacher I admire. Not only do you teach the students the subject matter in a manner which they understand and retain, but also in an enjoyable atmosphere. You have been a wonderful friend and most patient teacher to me. I thank you.

Many teachers (56%) worked with other teachers in their schools, co-teaching the units and sharing teaching ideas. At times, the project also promoted team teaching across disciplines. Some teachers reported that this was a new experience for them.

> All three of us . . . teachers have decided to work together — this is a first for us! Because the topic has several aspects, we decided to put the two classes together. Now, children who never would have talked to each other are working together, and I think it will last.

For some teachers, collaboration was related to the network, which was used by teachers to seek partners for joint projects. For others, the network activity was simply the context in which this collaboration was stimulated, although it could have arisen without the network. In addition, more than half the teachers (58%) involved other members of the school or local community (such as school administrators and parents) in the project.

Patterns of Teacher Participation

Here two networks are contrasted. In the Science Teachers' Network, administered by the Harvard Graduate School of Education, teacher support and development were not specifically linked with any curriculum. The study did not follow the teachers into their classroom. In contrast, the TERC Star Schools project offered an integrated program that linked technology, curriculum, and teacher support and documented evidence of changing classroom practices.

The Science Teachers' Network

The Educational Technology Center at the Harvard Graduate School of Education established a telecommunications network in December 1985 that focused on teachers, in an effort to reduce teacher isolation and provide a vehicle for staff development (Katz, McSwiney, & Stroud, 1987; Katz, Inghilleri, McSwiney, Sayers & Stroud, 1989). Secondary science teachers from eastern Massachusetts were recruited, including a group of recent graduates who knew each other well. Messages could be sent privately or placed on public forums, organized by function (e.g., the Notice Board forum) or by topic (e.g., the Chemistry forum).

The findings in this study were analyzed in terms of technical and logistical difficulties experienced by participating teachers; social issues of managing and facilitating group process on the system; and substantive content issues concerning contributions to the designated topics of the conference. A summary of findings is illuminating.

Seventy five teachers signed on; 45 stayed with the project (60%). About one-quarter logged in once or more a week. Most teachers read ten or more times as many messages as they wrote, that is, they used the network as a resource. About one-quarter wrote one or more messages a week—an average of one every two weeks. The average number of messages read was five per week. Having a computer at home affected significantly rates of logging on. The researchers expected message writing to increase logarithmically with net membership—in fact, it ran parallel

The pattern of communication varied depending on the extent to which participants knew one another. In a typical sample week, 32 messages were sent on the network. Of these, 63% were sent as private mail to individuals, 29% were posted to the public forum, and 8% were sent to both. Three-quarters of participants attended a training meeting, and this correlated positively with the amount of public writing. Teachers who had taught longer knew more members and wrote more. A group of recent graduates, wanting to stay in touch, wrote messages with a large social content. Teachers who were unacquainted with each other wrote messages about very specific topics rather than about general science: the exchanges centered around making inquiries, answering inquiries, and offering unsolicited information on rather discrete topics related to science teaching in the classroom.

In two conferences whose participants were mainly unacquainted with each other, almost half the messages were responses to previous messages, indicating that the network was indeed encouraging exchange. The network appealed especially to teachers who were more isolated professionally. Teachers with fewer informal contacts with colleagues outside school logged in and read more, and their perception that the lack of colleagues was a difficulty correlated positively with the extent of their public writing.

The TERC Star Schools Project

The TERC Star Schools project linked a large number of teachers (932) across the country (see Note 7). The project aimed to promote a total educational experience, of which the network was only one part. In addition to the network, there were 12 innovative curriculum units, purpose-built software, and a training program carried out by 12 Resource Centers across the country.

Introducing innovative curricular approaches demands ongoing teacher support, and heavy use of the TERC Star Schools telecommunications network to administer the project is one example of the importance of this support. The layered, distributed support structure that TERC adopted incorporated a mixture of local support from Centers around the country and on-line support in a variety of modes. Messages were exchanged between TERC, the Centers, and teachers. Such exchanges, which focused on organizational and technical concerns, provided an organized, efficient way to relay information to participants. Trainers, cluster chairs, and scientists served as resources for participating classes, providing on-line support and facilitating project goals. Overall, of all the messages sent, 59% were related directly to the curriculum, 33% focused on network coordination and administration, and 8% on personal issues.

On average, teachers reported that they used the network frequently. Forty percent used the network three or more times each week, and 48% used it once or twice each week. The remaining teachers (12%) used the network less than once each week. Teachers reported that they used the network for varied purposes, primarily for exchanging ideas about unit activities, for requesting and giving technical support, and for analyzing data. Interestingly, teachers and students sent approximately the same number of messages, demonstrating that teachers shared the responsibility of sending network communications with their students.

Promoting Teacher Change

TERC's evaluation instruments paid particular attention to the issue of teacher change. TERC did not expect all teachers suddenly to change what they were doing, but there are clear indications that participating in the Star Schools project was a very rewarding experience for many teachers, prompting them to both use and value more open-ended, collaborative teaching approaches and new evaluation methods.

A substantial number of teachers reported that they implemented the Star Schools curriculum units in a different way from their usual approach to teaching science (57% in Period One [October, 1989 - January, 1990], increasing to 78% in Period Three [April - June, 1990]). In specifying the differences, teachers reported that the open-ended nature of the activities encouraged them to adapt or modify their teaching methods; that their students carried out more group work than usual; and that

collaborative work in their classes resulted in a positive experience for them and their students. Almost all teachers (95%) reported that their students worked in small groups to carry out in-class activities. Forty-three percent of the teachers noted this was a change from the way they typically had organized their classes. Teachers commented:

> Students who would normally never associate [with one another] collaborated on their designs. Students solved a problem without the teacher giving them any solutions and [found] that a number of solutions were successful.

> With more [class] discussion, group problem solving, and student-centered learning, issues arise that would not ordinarily. Examples would be who would manage the group . . . and differences between inner-city, rural, and suburban responses to identical polls.

Many teachers reported that the unit activities extended beyond their regular curriculum. In carrying out the unit, most teachers (80%) raised concepts and issues that they normally did not discuss with their classes. An important role of the network is to connect teachers and students to scientists actively engaged in research. One of the most extended exchanges over the network took place between a class studying radon and a participating scientist. The class was concerned about high radon readings, and the scientist's responses gave the students a taste of the process of investigating possible reasons for these readings.

Star Schools teachers appreciated the role of the innovative curriculum in the success of the project; however, there was varying effectiveness among units. Some units, such as Descent of a Ball and The Solar House, were particularly successful in encouraging student inventiveness, but others, such as Radon, were less so. On the other hand, Radon was especially successful in helping students to see science as a collective enterprise. The math units (Connectany, Iterating Functions, Koetke's Challenge, and Triangle Chaos) were successful in increasing student observation skills. The Weather unit was effective in helping students to increase their observation skills, but did not particularly encourage students to reflect on the significance of their results.

Some units lend themselves more easily to network communications, providing specific suggestions for how to integrate the network into project activities. Some teachers felt that the units did not take sufficient advantage of the network: network activities, in their view, should be an integral part of the activities, not an add-on feature.

Evaluators saw a change in classroom dynamics. For example, there was a greater initiation of conversation by students on the network than is usual in traditional classes, where the standard, so-called IRE pattern is initiation by teacher, response by student, evaluation by teacher. This difference has been found in other studies (Goldman & Newman, 1988).

Although the Star Schools curriculum specified no particular means of evaluation, 81% of the teachers reported that they had evaluated their students' work, and (50%) of these teachers reported that they used a new approach in evaluating their students. Teachers used primarily non-traditional means of assessment, such as student participation in discussions (60%), hands-on activities (55%), and group skills (54%). Traditional evaluation approaches—such as quizzes (15%) and tests (9%)—were used less frequently.

Focusing on Student Outcomes

This paper provides examples of several studies dealing with the effect on students of their participation in telecommunications activities. In this section, more details are added, drawn mainly from two TERC projects: Star Schools and the National Geographic Kids Network. Direct quotes from students and from teachers about their students help to flesh out the quantitative information.

Which Students Benefited and How?

One important result of the TERC Star Schools project was progress in addressing the needs of disadvantaged students. Teachers reported that students who were typically less successful academically were better served by the Star School activities —which included hands-on and technology-based activities—than by the regular curriculum. Teachers were enthusiastic about the better performance of learning disabled and minority students in the Star Schools setting (see Table 1). Teachers gave specific examples of the benefits of a hands-on, technology-based approach to teaching science to students with learning difficulties, both with regard to improving self-esteem and in increasing understanding of the material.

> Some of my less academically-inclined students became "master supervisors" in their groups. One male in particular has taken on a complete change in personality and performance after his [solar] house was one of the most successful. He just displays a confidence I didn't see (nor his peers) before this unit. Learning styles were so evident to me while observing my students complete the unit. It gives me new insight into better teaching methods.
>
> As a matter of fact, I asked three students from the LD [learning disabled] classes to participate and one practically took over the project—certainly his group. He was one of five; four were regular students.
>
> One student who shows no interest (or relatively little interest) in completing assignments became the best worker when it came time to use the network, all aspects from editor to gathering data to learning the graphics program.
>
> Some of the poorer students were very successful with this unit. They would get to class early so they could work on the computer.

Table 1

Serving Diverse Student Populations:
The Regular Curriculum vs. the Star Schools Activities

(Percentage of teachers (n=184) reporting "very" or "extremely well"—the two highest ratings on a five-point scale.)

Promoting students' interest in science	Regular Curriculum	Star Schools Activities
Male students	51%	73%
Female students	47	66
Minority students	43	59
Students with poor academic performance	16	49
Encouraging students to take leadership roles		
Male students	31%	61%
Female students	28	55
Minority students	20	44
Students with poor academic performance	12	38
Improving students' understanding of academic content		
Male students	54%	66%
Female students	52	64
Minority students	43	58
Students with poor academic performance	24	38

Hands-on activities that rely on visual and manual skills can elicit students' strengths. This is true for all students, but most especially for students who are failing academically. Technology-based activities employ a variety of modes of representation, for example, the graphics screen provides interactive feedback and supports spatial problem solving. Such features allow the preferred modes of individual students to emerge, enabling them to succeed in an academic setting. Working to students' strengths in this way has far-reaching implications for science and mathematics education, and it is important to highlight these advantages so that the teaching community at large can come to appreciate their significance.

One example of the network approach with high achievers is the RING project, established by Indiana University for gifted students in rural areas (Southern & Spicker, 1989). In this project, activities were supported by an electronic network, together with a videotape exchange and two face-to-face meetings. Faculty members acted as consultants and mentors for the students as they carried out an environmental unit and a heritage unit. The network involved 200 students in grades 4-8 and 30 teachers. A pilot study revealed numerous problems, including poor quality telephone service in some rural areas, the high cost of long distance calls, and the timing of activities (for example, the winter field trip camera froze). Over the next two years, student participation climbed and student information requests and social contacts increased sharply. The number of faculty assistance requests also rose, to an average of three to four weekly. Important features contributing to success were that students had met and established contacts across sites at an early stage in the project; and that students needed information from each other. Teacher participation was, however, less successful. Several teachers were openly technophobic and tended to communicate by more standard means. Some were uncomfortable in directing independent inquiry and swung between totally unstructured, unspecified demands and rigid, highly structured assignments.

A Student Point of View

During the second year of the TERC Star Schools project, TERC collaborated with its Resource Centers in an investigation designed to obtain the reactions of participating students across the country (Weir, Krensky, & Gal, 1990, 1991). TERC was interested in probing student perceptions of the nature of science and the scientific process, student understanding of what scientists do, and attitudes to scientific challenges and to a possible science-related career. Students were interviewed before and after their Star Schools experience. The sample consisted of 80 students (40 males and 40 females) from 22 classes (grades 7-12) in 8 states (55% suburban location, 22.5% rural, and 22.5% urban).

Overall, three-quarters of the students were enthusiastic about Star Schools activities, and the same percentage perceived a difference in these activities compared with their regular science class. Signs of positive change among students included a high level of student interest and a new awareness of the importance of being active

learners. Students commented that the shift from lecture and instructional teaching to student-controlled team work was very apparent and welcome. This change took place in the context of a network-based project, in which teachers received support for changing the way they organized their classes.

In the pre-Star Schools interview, students expressed general dissatisfaction with the way classes were carried out, while in the post-Star Schools interview, they were more explicit about what they wanted. In explaining why they liked Star Schools, students introduced an issue that had not arisen in the pre-activity interview, namely, a strong preference for learning both on their own and from other students. It was as though participation in Star Schools introduced them to the possibility of being in control of their learning, of being probed about their knowledge as opposed to being told what to know, and of having input to the experimental design rather than being confined to a ready-made experiment. One student commented:

> We're given, like, basically how passive solar heating works and stuff, but we kind of had to find out for ourselves, you know? Discover it, because sometimes when you're told something you just don't understand it, but this way you understood in your own way. It wasn't like somebody trying something and you just memorizing it.

Students preferred the way collaborative arrangements were implemented in Star Schools compared to their previous experience of group work. Students described their previous experiences working in groups where the teacher controlled the communication process. TERC's curriculum materials demand a degree of autonomy and self-direction, with recognition of students' own ideas. Students talked about "working and thinking in teams." In reporting their classroom activities via the network, students were extremely enthusiastic about their group efforts. For example, one student remarked:

> Overall I think this [project] was something I would never forget. It was a great experiance [*sic*]. I learned about other schools and what questions they have been wanting to ask us. This gave us a chance to learn about other schools all around us. This also gave us a chance to get to know people in our class better. We got better acquainted with other people.

Over half the students remarked that the curricular topics in the Star Schools curriculum were different from those in their regular science class. For many students, studying topics relevant to the outside world and to their own reality was important.

> I didn't know anything about radon and [before this unit] I didn't care. I never really cared about our environment . . . [The unit] started to make me think about things and everything about recycling and stuff like using aerosol cans. I really started, I feel bad now when I use hair spray, you know? And I'm starting to really understand that people aren't just telling me to, aren't just teaching me things for nothing. I really have to use what people teach me, you know?

> Building the house. Gee, that was . . . it was something that I wouldn't expect that we would do, something like solar houses and stuff, it's just, people hear about it all the time. It's something that's kind of interesting to most people. I think of school as

a little bit behind and I was kind of impressed. I was like, hey this is what's going on outside.

Students appreciated the excitement and importance of investigating questions for which the answers were not known beforehand. Several students mentioned how their participation in Star Schools had involved them in thinking more deeply about their work. Associated with this was a significant shift toward a willingness to work with the more open-ended inquiries that are part of the Star Schools approach.

> Oh . . . we didn't have to write as much, or, you had to think more. It wasn't like writing data charts, because data charts are really easy, you just copy things from the board or you do math, but this you have to sit down and think. You had to use your brain a little more than usual, so that's how it was different . . . I think if we didn't do this radon activity I wouldn't have to use my brain at all the whole year. This is the only time that I really had to think and I really, like, I had to struggle a little, you know, and I'm not really used to doing that in science.

Scientific investigation requires an ability to respond to the challenge of the unknown and to tolerate ambiguous situations. Indeed, science is the process of making sense of such situations, of finding appropriate explanations for the ambiguities and unknowns. TERC was interested in exploring student attitudes to the challenge of new and uncertain situations, and included in the interview a set of six questions designed to probe these attitudes. A small but consistent change can be noticed when comparing responses before and after the Star Schools experience (see Table 2). The percentage of students with a preference for simple, familiar questions with one straightforward answer lessened, with a corresponding increase in those who preferred unfamiliar questions quite difficult to solve, with no straightforward answer or one right approach.

Based on their responses to the six questions, students were rated on their overall style in terms of whether they preferred to *Tackle the Known* or to *Tackle the Unknown*. In both interviews (pre- and post-Star Schools activity) the majority of students preferred the *Known*, but the number who felt that way decreased from 80% before to 64% after the activity ($p<.005$).

The project served to expand students' views of science. Students appeared to develop a more intimate knowledge of science and scientists and a decreased sense of alienation from the scientific enterprise. From the fall to the spring, the percentage of students who had a more complete picture of scientists increased from 31 to 55%, with a corresponding drop in the number of those who had a stereotypical picture.

Table 2

Students Report on Their Preference for Tackling the Known vs. Tackling the Unknown
(Students' Interview, n=80)

Types of Questions Preferred	Fall	Spring
Questions similar to ones you've considered before	75%	25%
Questions that don't have one right approach	61	70
Questions that are quite difficult to solve	47	50
Questions that you are confident you know the answer to	80	68
Questions that don't have a straightforward answer	33	48
Questions that are really different from anything you've considered before	64	72
Overall style		
Prefers to tackle known questions	79	64*
Prefers to tackle unknown questions	16	27*

* $p < .005$. Degree of significance was calculated by Chi-Square Test.

Evaluation of the NGS Kids Network

During September 1989 and January 1990, TERC carried out an evaluation of NGS Kids Network activities. Again, as in the Star Schools project, telecomputing in this project was part of a larger endeavor to support innovative curriculum activities.

Three fourth- and fifth-grade classes who carried out the *Hello!* and *Acid Rain* units participated in pre- and post-written tests, oral interviews, and classroom observations. Findings in experimental classes were compared with those in a control class. The following selection of evaluation findings was taken from the NGS Kids Network Evaluation Report (Mokros, Goldsmith, Ghitman, & Ogonowski, 1990).

1. Students demonstrated significant gains in their ability to organize and represent data. Students in the NGS Kids Network group demonstrated significant pre- to post-test increases in the use of conventional graphs for organizing a small set of observations, while the control group did not.

2. Students' skill at data interpretation also improved significantly. More students were able to make observations about the data set on the post-test. For example, while 34% of the NGS Kids Network students were unable to make even a single comment about a data set on the pre-test, this proportion dropped to 7% on the post-test. In addition, students were better able to use available data to draw a conclusion on the post-test than they were on the pre-test.

3. Students demonstrated gains in specific content areas: significant gains in place knowledge (19% increase, from 71% pre-test to 90% post-test), and significant increases in the ability to use latitude and longitude to identify map location (25% increase, from 25% pre-test to 50% post-test). Students' understanding of the factors contributing to acid rain and their ability to reason about the impact of these factors improved significantly from pre- to post-test: For example, causal explanations of the relationship between factory emissions and wind patterns increased by 26% (6% pre-test to 32% post-test).

4. When the performance of learning disabled (LD) students in the sample was compared with the responses of non-LD students, their gains paralleled the improvements observed in the whole sample, with respect to graph use, comments about data, mapwork, and level of explanation they offered for the cause of acid rain.

   Although no comparisons were made between LD students' learning using NGS Kids Network materials and learning using other science curricula, "This 'first look' at the success of the NGS Kids Network units with respect to special populations is nonetheless encouraging" (Mokros et al., 1990, p. 49).

5. Interviews demonstrated that the students' understanding was in fact richer than had emerged from their written answers. Measures requiring short written responses are, by necessity, constrained in terms of the richness of problems to be solved and the means of accessing children's thinking about how to solve them.

Predicting Network Success

Since different networks have different goals, the criteria for success vary. Factors that affect the degree to which teachers begin and persist in their involvement include ease of access to the network, the level of motivation or obligation to use the system regularly, the extent to which the activities fit into the teacher's available time, and the degree of support from the school administration.

A striking feature of the Harvard Science Teachers' Network study was that having a computer at home significantly affected rates of logging on, reading, and writing, both private and public. This is a specific instance of a more general finding: Ease of access is crucial to success. This applies even at the university level. In a comparative study, Riel and Levin (1990) assessed several groups of similar networks. For example, they compared two university networks, one successful and one unsuccessful. In both cases, participants knew each other and shared common interests. The most important difference was in ease of access: in the successful case, participants accessed the network in their offices, whereas in the unsuccessful case, they had to walk down the corridor to a public machine.

Agresto (1989) described a fascinating telecommunications project at Boston University designed to train and mentor history teachers to use the Federalist papers. A lesson plan was provided and the idea was interesting, but the implementation not good. There was a mismatch between the access required to complete the unit and teacher access to the network: some teachers had to travel to a site to get on-line.

In the TERC Star Schools project, many teachers reported struggles with the school administration around this issue of access to the means of communication. For example, telephones are generally not located in classrooms, and for a teacher to get an outside telephone line is an unheard of luxury for many schools, particularly those in inner cities. In addition, many teachers reported that their network use was restricted because school computers were available only in certain locations at certain times. Approximately one-half of the teachers had access to only one computer (and the average class size was 24 students). In addition, although two-thirds of the teachers had a computer in their classroom, less than one-half also had a modem within easy reach in the classroom. One cannot benefit from a telecommunications support system if one cannot get on it. A teacher explained:

No computer in room; computer locked in A-V room, and then used in department head's office. This arrangement was too inconvenient for a course that has a computer as one of its primary resources.

For many teachers a major problem arose with regard to the time demands associated with the Star Schools activities. Some teachers lost their initial enthusiasm when they found out what was involved and did not participate as actively as they had first intended. Other teachers decided not to participate at all. To learn more about why teachers did not follow through on their original plans, TERC asked teachers who signed up to participate but then changed their minds to explain why. Sixty-nine respondents attributed their change of plans to four major reasons. Approximately half (49%) reported that lack of time was the primary reason. Some teachers had problems obtaining the necessary equipment to carry out project activities (37%), had an unexpected illness or illness in the family (8%), or encountered a logistical problem—such as signing up too late or not being "aware of the options available" (6%).

Clearly, the criteria for success will vary with the purposes of the network. Katz et al. (1987) distinguished two different approaches. If interest is in maximizing group solidarity, then peripheral members (e.g., those who only read) should not be admitted. If information sharing is the goal, then a large membership may be required with accommodation for variable log-on frequency. Riel (1990) made a similar distinction between two kinds of interaction. One is the conference format, which supports a variety of tasks with distributed control, in which participants come and go, and pick and choose what they are interested in. In contrast, another type of organization resembles a task force, in which participants come together to achieve a specific task that is centrally controlled.

Conclusions

As this paper illustrates, introducing telecommunications into an educational setting is a multi-textured affair. When given the opportunity, some teachers participate actively; others do not. Recall the concern to collect evidence for the claim that telecomputing has the potential to catalyze educational change: An electronic network cannot play a role in generating change for teachers who do not use it.

This survey of projects revealed several factors that play a role in determining successful participation. In all studies, ease of access was found to be a crucial predictor of success. Providing an efficient system is the first requirement. Put simply, teachers do not have the time to mess around with baroque configurations that break down, take time, and demand attention that detracts from their educational usefulness. Second, support from the school administration is necessary to ensure the physical implementation of the network system. Minimally, a teacher needs ready access to a computer, a modem, and an available telephone line at times convenient to her/his schedule.

When teachers do participate, the pattern of communication tends to vary with the extent to which participants have met face to face (Katz et al., 1987; Gal, 1991). The network appealed especially to teachers who were more isolated professionally. An interesting common finding is that teachers tend to read more messages than they write. Being a silent onlooker could be thought of as the first stage in network participation.

When teachers do participate, there is good evidence that benefits accrue. The reports presented confirm the usefulness of telecommunications networks in encouraging collaboration at several levels in the educational system. For example, in the TERC Star Schools project, teachers reported increased collaboration among their students. They themselves worked more with other teachers in their schools. Students valued collaborating with students in other parts of the country. Teachers related to other teachers across the country in a variety of ways, and the network was used to effect administrative coordination among participants.

With respect to teacher change, a substantial number of teachers in the Star Schools project reported that they implemented the units differently from their usual approach to teaching science, that the unit activities extended beyond their regular curriculum, raising concepts and issues that the teachers normally would not have discussed with their classes. Star Schools teachers appreciated the role of the innovative curriculum in the success of the project, and many teachers reported that they used a new approach in evaluating their students.

It should be noted that the Star Schools network was successful in providing a forum for voicing teacher concerns. Teachers were able to let TERC know in detail about the difficulties they were having at the time the difficulties occurred. It seems clear that this aspect of network use could serve an important function in facilitating the implementation of educational innovations. Education provides a community of learners, each of whom needs a customized telecomputing tool. As Beverly Hunter (1990) observed: "The most effective networks are likely to be those that are designed to support a shared vision of the collaborative social and organizational reality desired by and for teachers and educational communities" (p. 6).

The effect on students was dramatic. Teachers reported that students who are typically less successful were better served by the Star School activities than by the regular curriculum. The student interview was particularly revealing: participation in Star Schools introduced students to the possibility of being in control of their learning. Students found it refreshing to have emphasis placed on their own knowledge and their own input to the experimental design rather than being confined to a ready-made experiment. Studying topics relevant to the outside world and to their own reality was important and involved students in thinking more deeply about their work. An encouraging result was the high number of students prepared to tackle new and unknown topics.

The changes reported by Star School teachers revolved largely around the use of new kinds of materials and new classroom practices. Whether this was accompanied by a change in teachers' beliefs about teaching is not clear from the reports. Changing beliefs about teaching takes time (Fullan, 1982), and to find out the extent to which this happens during participation in a telecommunications project will require more in-depth and long-term research than has yet been undertaken. Our recommendation is that such a study must include explicit network discussions about pedagogy designed to promote the growth of a self-reflective practitioner.

Predicting which teachers might be ready to change their beliefs and practices has been the focus of many studies reported by Fullan (1982). In one study, teacher professionalism (aggregate level of education as indicated by a master's degree) in a high school district was positively correlated with initiation of change by teachers and adoption of innovations for college-bound students, but negatively correlated with adoption of innovations for high school terminating students (Fullan, 1982). This study also found that a higher ratio of district support staff—so-called linking agents—facilitated the adoption process. How this works in the context of a network would need to be part of further research.

The importance of a supportive school administration in innovation adoption (Fullan, 1982) was manifest in the Star Schools project. In implementing the changes incorporated in the Star Schools materials, a recurring theme is teachers' struggles with the school administration. Innovative curricula require changes in classroom scheduling and evaluation methods that are difficult for teachers to implement without the support of school authorities. Existing organizational settings wield awesome power in shaping behavior in schools, and educational change comes slowly. Given how schools are currently structured (the graded school, self-contained classroom, a segmented curriculum, etc.), teachers pay a high price in trying to put into practice different views of learning, teaching, and the roles that adults play in school (Cuban, 1989). In evaluating the TERC Star Schools telecommunications project, TERC's recommendation was that the Star Schools approach be implemented on a system-wide basis to optimize support from school administrators and policy makers who decide what teachers in their area do and how they do it (Weir et al., 1990).

A concern for equity in access to the benefits of technology led Michael Cole and his colleagues in San Diego to make an interesting sociological point (Laboratory of Comparative Human Cognition, 1989). They regret that technology has up to now tended to widen the gap between the advantaged and the disadvantaged, because more computers are available to middle- and upper-class children than to poor children. Further, computers for poor children tend to be used for rote learning rather than for the cognitive enrichment they provide for middle- and upper-class students. Cole and his colleagues speculated that access to cheap computers linked in telecommunications networks with appropriate support could help to reverse this trend. In the extreme, if a school or a class has only one computer, using that

computer to telecommunicate could be about the best, most cost-effective use one could find, since so much of the activity could be off the computer, which would be used only for downloading and uploading messages.

The survey findings show that when telecomputing is embedded in an integrated program of teacher support and curriculum development, with an involved school administration, it can be a powerful agent of educational change. This approach is innovative, and we are learning all the time about how to run a network more effectively and about what kind of curriculum best supports its use. Many questions remain, and additional research is needed in critical areas such as depth of change among teachers participating in an electronic network.

Notes

1. The Bank Street Earth Lab project, started in 1986, created a local area network implemented in two inner city sixth-grade classes. It introduced a geography-based science curriculum that relied heavily on students working collaboratively in groups. Interestingly, that change in classroom organization persisted into the regular, non-project classes (Goldman & Newman, 1988; Newman, Goldman, Brienne, Jackson, & Magzamen, 1989). To evaluate the project, the researchers analyzed network messages, video records and classroom observations, and interview protocols.

2. One of the most fully described educational networks is the Alaska QUILL Network (Bruce & Rubin, in press). Five Alaskan school districts and the University of Alaska-Fairbanks, Department of Education, formed a consortium and provided funds for a part-time coordinator for 25 participating teachers and administrators. The predominant use of the network was for teacher communication. The central classroom activity about which teachers communicated was writing as a form of problem solving, with an emphasis on revision as a necessary part of that process. Bruce and Rubin describe situated evaluation as a way of analyzing the process of use of an innovation in a variety of contexts.

3. The Educational Technology Center at the Harvard Graduate School of Education has been conducting an experiment in computer-based conferencing since 1986 to facilitate collegial exchange among science teachers. The researchers (Katz, McSwiney, & Stroud, 1987) undertook an ethnographic study of the use of the network, using a sample of saved network messages and machine log files, data from telephone interviews of teachers, and teacher questionnaires.

4. LabNet is a telecommunications teacher enhancement program that links physics teachers in grades 9-12 on a network in order to support the development of projects incorporating microcomputer-based laboratory tools. Teachers meet face-to-face at summer training workshops. Preliminary evaluation shows the importance of this personal interaction in fostering productive use of the network (Gal, 1991).

5. The InterCultural Learning Network started as a collaboration between children in Alaska and suburban San Diego to produce a newspaper called *The Computer Chronicles* (Reil, 1985), and it culminated in an expanded Network (Levin, Riel, Miyake, & Cohen, 1987; Riel, 1987; Levin, Kim, & Riel, 1988). In this network, elementary, middle, and secondary teachers and students, as well as undergraduates, graduate students, and faculty in California, Illinois, Connecticut, Alaska, Hawaii, Puerto Rico, Mexico, Japan, and Israel engaged in joint newspaper-writing activities on such topics as cultural celebrations, water conservation, and local social problems of concern to the students. The

InterCultural Learning Network formed a tight-knit community, several of the site coordinators having worked together previously in face-to-face settings. Typically, a small group of classrooms (3-8), geographically separated, worked together on specific topics. The AT&T Learning Network is a commercial service that evolved out of this research project.

6. NGS Kids Network is a collaborative project of TERC, the National Geographic Society, and the National Science Foundation that brings a telecommunications-based science curriculum to grades 4-6 classrooms around the globe. Students participate in large-scale, cooperative experiments and share their results on the network. Unit topics, developed by TERC, include acid rain, water quality, weather, trash, health, and energy.

7. The TERC Star Schools project was an ambitious, two-year network science program involving many participants around the United States in an integrated program of teacher support and curriculum development. The project can serve as a model of how to use technology to provide continuing teacher training while achieving widespread dissemination of innovative ways of doing science and mathematics in the classroom. After a pilot program in the Spring of 1989, a total of 932 teachers signed on during the 1989-90 school year. Classes carrying out the same unit were grouped together in clusters. Each cluster included approximately 15 classes, grouped by grade level. Most clusters had a cluster chair to facilitate network exchanges. Curriculum units included topics in science (Radon, Weather, Polls and Surveys, Solar House, Descent of a Ball, and Trees) as well as four innovative math topics (Connectany, Koetke's Challenge, Triangle Chaos, and Iterating Functions). An extensive evaluation was undertaken using a database of stored network messages, teacher questionnaires, some classroom observation, and student interviews pre- and post-activity (Weir, Krensky, & Gal, 1990). Evaluators followed intensively the activities of selected participants (116 teachers and cluster chairs in eight clusters) who used specifically-designed software that automatically saved a copy of all messages into a network database. Center Directors, trainers, and TERC staff also used this software.

8. The TERC Global Laboratory project links teachers, students, and scientists in an international program of ecology research. Over 80 schools worldwide are involved in physical and biological monitoring, modeling, data analysis, and experimentation activities. TERC developed low-cost instrumentation and curriculum materials to support these monitoring activities.

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